Analysis of the Short VLBI Baseline at the Wettzell Observatory

Iván Herrera Pinzón [1], Markus Rothacher [1], Jan Kodet [2], Ulrich Schreiber [2]

Abstract Within this work, we present results on the assessment of the short baseline between the co-located VLBI telescopes at the Geodetic Observatory in Wettzell (Germany). VLBI sessions between July 2015 and June 2016 are processed using the VLBI capabilities of the Bernese GNSS Software to estimate geodetic parameters. Through the use of several parametrization approaches, this analysis shows a sub-millimeter agreement of the VLBI-derived baselines with the terrestrial measurements (local ties).

Keywords VLBI, co-location, short baselines, local ties, Terrestrial Reference Frame

1 Introduction

Short VLBI baselines, with baseline lengths of less than a few hundred meters, are much less suffering from errors in quasar coordinates, Earth rotation parameters, and tropospheric delays than long global baselines, and they are thus particularly well-suited to identify local effects and instrument-specific biases. These intra-technique experiments are expected to provide insights into systematic technique-related errors, eventually leading to a better agreement with the local ties at the fundamental sites. This constitutes a pre-requisite to improve the realization of the International Terrestrial Reference Frame (ITRF), to fulfill the GGOS goals in terms of accuracy and stability [6].

1. Institute for Geodesy and Photogrammetry. Swiss Federal Institute of Technology in Zurich (ETHZ)
2. Geodetic Observatory Wettzell. Institute for Astronomical and Physical Geodesy. Technical University Munich

For this purpose, the estimation of geodetic parameters (station coordinates, zenith tropospheric delays, clock offsets, and Earth orientation parameters) was performed for the short VLBI baseline at the Fundamental station Wettzell in Germany, realized by the legacy 20-m dish Radio Telescope Wettzell (RTW) and the new 13.2-m diameter TWIN Telescope Wettzell (TTW1). A tailored parametrization was developed, to work out the advantages and disadvantages of short baselines. Then, the main task was to compare these derived parameters with the terrestrial survey (for the coordinates) to study the performance of the VLBI solutions.

2 Methods

The data set used corresponds to 57 VLBI sessions of the IVS observing program, which contain the baseline RTW–TWIN1 [1]. These geodetic sessions were carried out between July 2015 and June 2016. Each session contains a subset of the stations of the global network. However, due to interference in cross-correlation caused by the presence of the pCal system in both radio telescopes, it was recommended to deselect the local Wettzell baseline after January 26, 2016. Therefore, the cross correlations of the short baseline are available only for 21 out of the 57 sessions. The VLBI data were taken from the NGS cards. Cable delays were applied to the data, when available. It is worth to notice that the cable delays for station TTW1 are not present, since the cable delay system was not available, so only those for the RTW could be applied. The NGS files were converted into baseline single difference files and processed in a tailored version of the Bernese GNSS

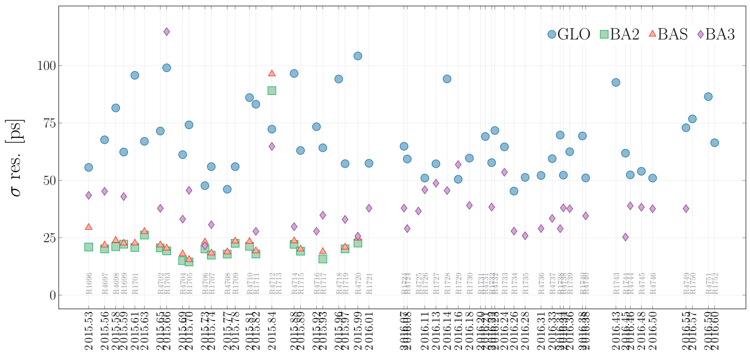

Fig. 1 Standard deviation of residuals per session [ps].

Table 1 Summary of the modeling and parametrization used.

	Global Sol. (GLO)	Baseline A (BAS)	Baseline B (BA2)	Baseline C (BA3)
Observations	All VLBI observations	WETTZ-WTZ13 observations	WETTZ-WTZ13 observations	NYALS-WTZ13 and NYALS-WETTZ
Coordinates	NNT/NNR w.r.t. ITRF2008	WETTZ constrained 1 mm	WETTZ constrained 1 mm	NYALS constrained 1 mm
Earth rotation	Rotation pole coordinates and UT1, 24 h intervals	not estimated	not estimated	not estimated
Troposphere	13 zenith wet delays VMF for every station and session	not estimated	13 zenith wet delays (VMF) for WETTZ in every session	13 zenith wet delays (VMF) for every station and session
Receiver clock	Two clock offsets for every station and session	Two clock offsets for WTZ13 per session	Two clock offsets for WTZ13 per session	Two clock offsets for WTZ13 per session

Software v5.2 [3, 7]. For the parametrization, four different approaches were designed, where the modeling of the dry atmosphere, the solid Earth tides, and ocean loading are common for all these solutions. The first approach (**GLO**) is a global solution, where all VLBI observations are used. The datum for the station coordinates is defined by a minimum constraint condition, i.e., with NNR and NNT conditions w.r.t. ITRF2008. Earth rotation parameters, for 24-h intervals, are determined as a continuous piece-wise linear function. Zenith wet delays are estimated as a piece-wise linear function with 2-h intervals, using the wet VMF model for mapping [2]. Receiver clock offsets are parameterized as a linear polynomial during the session, for each station except for WETTZELL. The second processing approach (**BAS**) is a short baseline solution, where only the RTW–TTW1 (WETTZELL–WETTZ13N) baseline observations are used. The datum for the station coordinates is given by constraining the coordinates of WETTZELL. Earth rotation parameters are not estimated, and receiver clock offsets are calculated every 24 hours for WETTZ13N, for each session. The main feature of this approach is that the troposphere wet delays between the two stations are not estimated, on the assumption that for such a small distance and small height difference, differences in tropospheric delays can be modeled. The third approach is a baseline solution (**BA2**), where only the WETTZELL-WETTZ13N baseline observations are used. Earth rotation parameters are not estimated and the datum and receiver clock offsets are defined in the same way as for the **BAS** solution. In contrast to the **BAS** solution, zenith wet tropospheric delays are estimated piece-wise linearly with a time resolution of 2 h and mapped with the wet VMF model for WETTZELL. Finally, to bridge the outage of data in 2016, a fourth processing chain (**BA3**) uses the station NYALES20, in Ny-Ålesund (Svalbard, Norway) with two baselines to Wettzell of ca. 3,300 km, to connect the two Wettzell telescopes. The datum for this solution is given by constraining the coordinates of the station NYALES20, while Earth rotation parameters are not estimated and receiver clock offsets are defined as in the **BA2** solution. Zenith wet tropospheric delays are set up as for the **GLO** solution. A summary of these strategies is shown in Table 1.

3 Results

3.1 Least Squares Residuals

To evaluate the quality of the estimation, the standard deviation of the residuals per session is provided. This step of the analysis is used to identify significant outliers. Session R1703 for the BA3 solution, and sessions R4712, R4716, and R4718 for the BAS and BA2 solution display an anomalous behavior (Figure 1). For the remaining sections of this work, these sessions are not considered for the statistical analysis of the results. The appropriate handling and down-weighting of the problematic observations is left for future work. After removing these sessions, the standard deviations of the residuals are 66.17 ps for GLO, 37.27 ps for BA3, 21.85 ps for BAS, and 19.90 ps for the BAS solution.

As expected, larger levels of noise are present in both global solutions (GLO and BA3), while the obtained standard deviations for the local solutions (BAS and BA2) is up to three times smaller. The improvement in the standard deviations obtained for the local baseline solutions supports the idea that these type of solutions are suitable for the precise analysis of the behavior of the local baseline, since the identification of error sources will be possible with more details than in the global solutions, where small effects are masked by the large residual values.

3.2 Clock Offsets WETTZ13N–WETTZELL

The parametrization used to calculate the clock corrections consists of two offsets per session with a linear behavior between these estimates. These two parameters may not accurately describe the session clock behavior during one session. To increase the time resolution and the statistical significance of the analysis of the clock behavior, a local baseline solution without the estimation of any parameter was done, where coordinates are given by the local tie and troposphere delays by models. In this way, the residuals of this estimation are equivalent to the clock corrections, plus the observation noise (and possibly other effects). Figure 2 shows the behavior for these residuals (straight lines, left axis) for sessions R4708 (left) and R4712 (right). Moreover, the deviations of these residuals/clock corrections w.r.t.

Table 2 Drift and RMS of the deviations from a linear fit for the VLBI clock estimates.

Session	VLBI Drift [ns/day]	VLBI RMS [ps]	Session	VLBI Drift [ns/day]	VLBI RMS [ps]
R4708	-18.032	16.6	R1715	-16.610	18.8
R1709	-18.188	25.3	R4716	-17.055	35.5
R4710	-18.160	21.5	R1717	-17.163	18.4
R1711	-18.423	28.7	R4718	-17.518	49.3
R4712	-17.832	85.9	R1719	-17.544	19.5
R1713	-16.922	118.0	R4720	-17.824	22.7
R4714	-16.422	23.1			

a linear fit are calculated (right axis of Figure 2), and are used to characterize the clock behavior. Notice, for instance, how these residuals follow a quadratic pattern for session R4712, which suggests that modeling the clock with two clock parameters per session is not sufficient for this session. Table 2 summarizes the estimated drifts and the RMS of the residuals w.r.t. the linear fit for the sessions containing the short baseline. With clock drifts in the order of -16 to -18 ns/day and RMS values of the same order of magnitude as the residuals in Section 3.1, these data provide clock information comparable to the clock estimates of the BAS solution.

3.3 Coordinate Residuals and Repeatabilities (WETTZ13N)

The coordinate residuals w.r.t. the ITRF2008, in an ENU system, are calculated and displayed in Figure 3. A smaller scatter is obtained, as expected, for the local

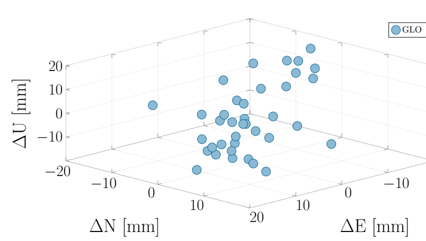

Fig. 3 Residuals per component [in mm] for the four approaches.

baseline solutions, where north and east components display a favorable behavior within a range of a few mm, while the height component shows a scatter about

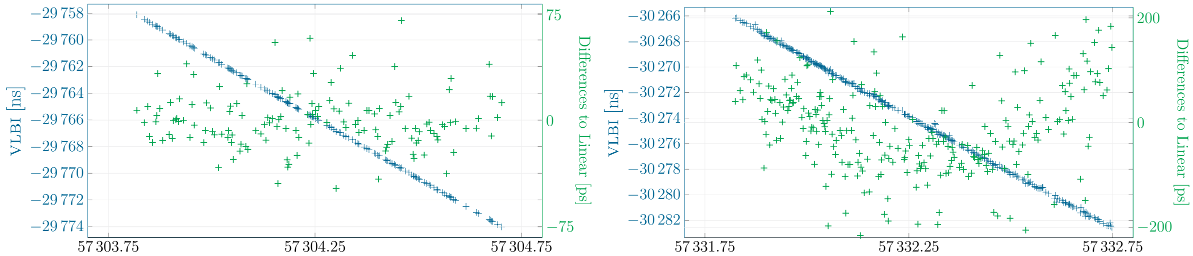

Fig. 2 Residuals from solutions without estimating any parameters (blue straight line) and differences to a linear fit (green scatter).

twice as large. Both global solutions (BA3 and GLO) show a significantly worse performance, due to the fact that most error sources grow with the baseline length. Nevertheless, these residuals do not exceed 10 mm. It is also apparent from Figure 3 that the estimation of the wet tropospheric delays is highly correlated with the performance of the height component, resulting in the larger scatter difference seen in the up component of the BAS and BA2 solutions. To compliment this analysis, the repeatabilities of the coordinates in an ENU system were calculated. The obtained values, $[1.21, 0.81, 2.84]$ mm for BAS, $[1.25, 0.85, 2.88]$ mm for BA2, $[4.53, 4.16, 9.14]$ mm for BA3, and $[7.11, 6.11, 9.51]$ mm for GLO, show in general higher values for the up component. The local baseline solutions BAS and BA2 display very good performance with values close to 1 mm and 3 mm, for the horizontal and vertical components, respectively.

3.4 Comparison with the Local Ties

The local ties from a terrestrial survey, described in [5], report a baseline length of 123.3070 m $\pm$ 0.7 mm. Baseline length differences w.r.t. this value are computed and represented in Figure 4. Moreover, the mean value and the repeatability (std. dev.) of the baseline length over the time series is calculated. This results in mean biases of -0.8 mm, -0.2 mm, -0.3 mm, and -0.1 mm for the GLO solution, BA3 solution, BAS solution, and BA2 solution, respectively. The corresponding repeatabilities are -4.9 mm for the GLO solution, 4.6 mm for the BA3 solution, 0.8 mm for the BAS solution, and 1.3 mm for the BA2 solution. The comparison of the baseline length shows an excellent agreement with differences clearly below 1 mm, albeit with much larger standard deviations for the global solutions. In addition to the baseline length, the differences per component w.r.t. the local ties are analyzed in an ENU system. Figure 5 displays these differences. Following the behavior of the repeatabilities, the up component shows a larger scatter, while the north component displays the best performance. This behavior is attributed to the orientation of the baseline, since RTW is located to the north of TTW1. From the four solutions, the BAS approach shows the best performance regarding the aforementioned indicators, on account of its parametrization, which is based on only data of the short baseline and estimates the smallest number

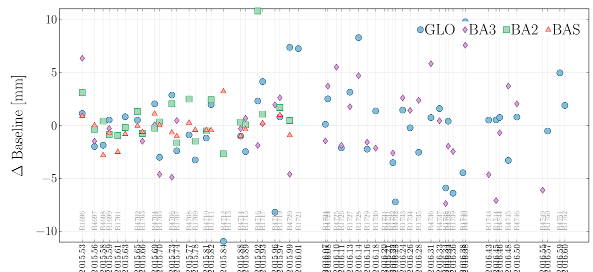

Fig. 4 Baseline length differences [mm] w.r.t. the local tie.

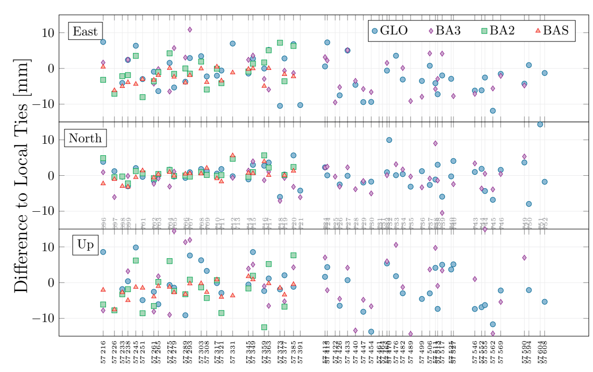

Fig. 5 ENU differences [mm] w.r.t the local tie.

of parameters (coordinates and clock offsets), which strengthens the estimated parameters. The vector of differences over the time series for this solution results in mean deviations of $[-2.04, -0.05, -1.60]$ and standard deviations of $[1.2, 0.8, 2.8]$ mm.

4 Summary and Future Activities

This work presents investigations on a short VLBI baseline, using several processing approaches in terms of local troposphere and clock parametrization. These solutions are subsequently compared with the local ties (baseline length and components), where a sub-mm agreement of the estimated baseline length with terrestrial measurements is found. The standard deviations found are about 1 mm and 3 mm for the horizontal and vertical component, respectively, and confirm the suitability of the BAS approach for the monitoring of VLBI short baselines. The strategy to avoid the estimation of the wet troposphere, as for such a small distance and small height difference, differences in tropospheric delays can be modeled, results in better coordinate repeatabilities, and thus is preferred for the study of the short baseline. Moreover, an analysis of the daily stability of the clocks was performed, where the deviations from a daily linear fit were considered. With daily drifts between -18 and -16 ns/day and average residuals of up to 50 ps, this analysis shows the limitations of the clock modeling and the need for further analysis, to reach the goals of accuracy and stability of GGOS. Future work will focus on the use of the local time transfer system, to improve the estimation of parameters.

Acknowledgements

The authors would like to thank the IVS [1] for providing the VLBI observations.

References

1. Behrend, D. Data Handling within the International VLBI Service. Data Science Journal (2013). doi:10.2481/dsj.WDS-011
2. Boehm, J., B. Werl, and H. Schuh (2006), Troposphere mapping functions for GPS and very long baseline interferometry from European Centre for MediumRange Weather Forecasts operational analysis data, J. Geophys. Res., 111, B02406, doi: 10.1029/2005JB003629.
3. Dach, R., Lutz, S., Walser, P., Fridez, P. Bernese GNSS Software Version 5.2. Astronomical Institute. Bern University (2015). doi:10.7892/boris.72297
4. Herrera Pinzón, I., Rothacher, M. Assessment of local GNSS baselines at co-location sites. J Geod (2018). doi:10.1007/s00190-017-1108-9
5. Kodet, J., Schreiber, K.U., Eckl, J. et al. Co-location of space geodetic techniques carried out at the Geodetic Observatory Wettzell using a closure in time and a multi-technique reference target. J Geod (2018). doi:10.1007/s00190-017-1105-z
6. Plag, H.P, Pearlman, M. Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020. Springer Berlin Heidelberg (2009). doi:10.1007/978-3-642-02687-4_9
7. Schmid, R. Zur Kombination von GPS und VLBI. PhD Thesis. Technische Universität München (2009)